Simulating Bet Hedging Strategies of Native and Exotic Annual Plants

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Background

Organisms need to adapt to a rapidly changing environment to maintain long term survival. One adaptation strategy is ***bet hedging***: sacrificing mean fitness for lower variance in fitness. Annual plants (which produce seeds every year) may bet hedge by ***delaying seed germination***, keeping a portion of new seeds in dormancy instead of letting all germinate in the upcoming year so that those dormant seeds can still germinate after, say, a drought severely reduces the adult population. ***Inferring how native and exotic annual plants specific to a region hedge their bets through delayed seed germination*** can shed light onto preservation of native species facing the impact of climate change.

Method

- We previously aimed to target native & exotic annuals in Rhode Island; however, due to varying collection methods and non-exhaustive coverage on these species, seed germination data are hard to estimate on a consistent scale.
- In order to address this gap in knowledge, we use a stochastic model to simulate competition between a wild-type (WT) population and a bet hedging (BH) population of the same initial size within the same species; we calculate the ***normalized probability of fixation*** (NPfix) of bet hedgers across all parameter values which serve as indication of adaptivity.

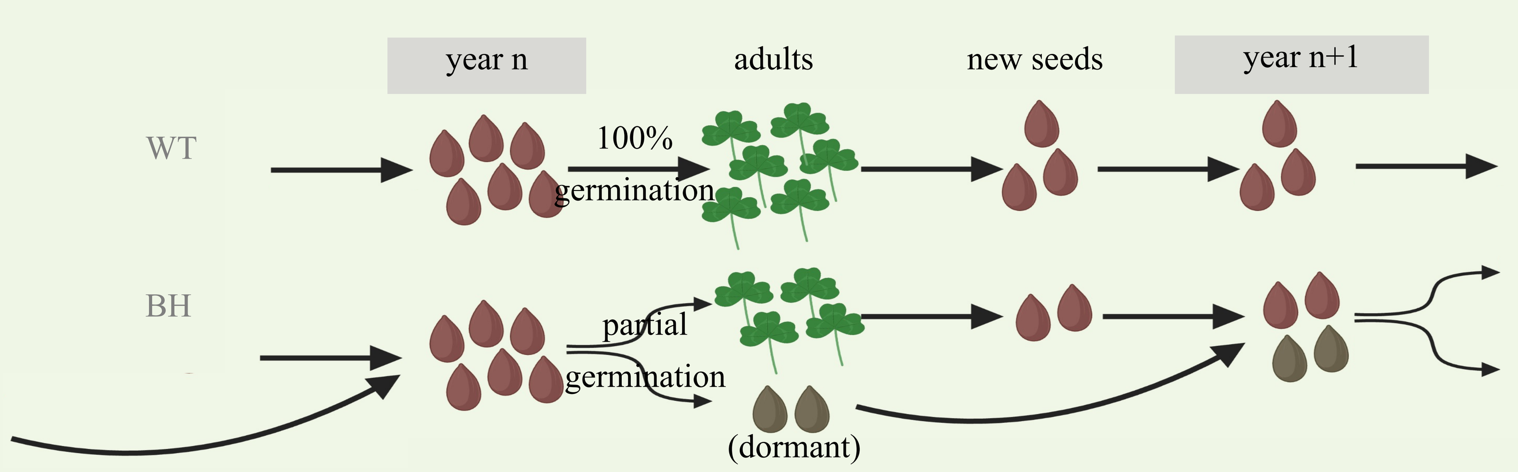

Figure 1. WT and BH generations in simulation

more on model + plots
github.com/nyin01

Parameters

- Carrying capacity (K=[10, 100, 1000])
- Germination rate (G=[0.25, 0.3, …, 0.95, 1.0])
- Selection coefficient (S=[0, 0.01, 0.1, 0.5, 1.0])
- Coefficient of Variation (CV=[0, 0.01, 0.1, 0.5, 1.0])

Model Validation

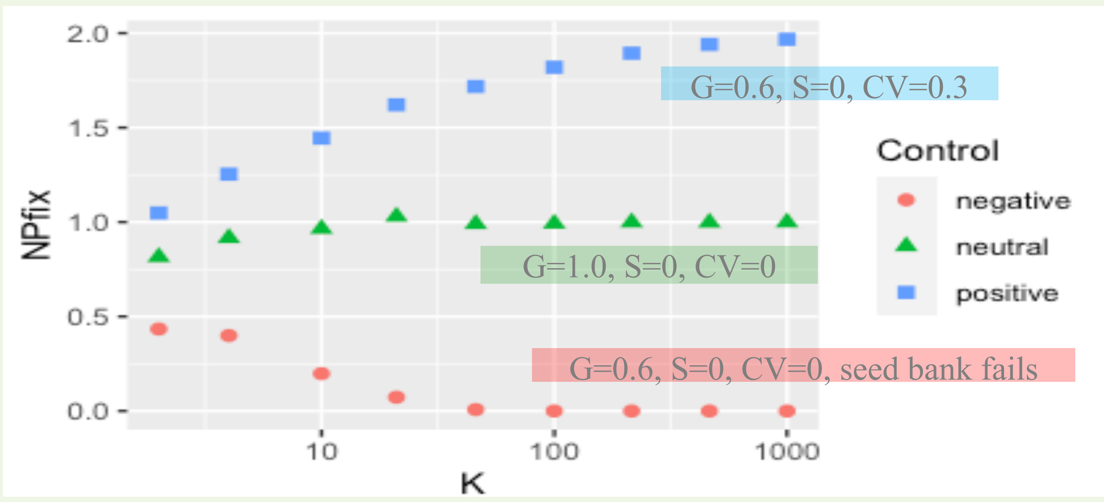

Figure 2. Normalized probabilities of fixation in control sets ***correspond to expected trends*** of probabilities of fixation of WT, beneficial, and deleterious mutations as carrying capacity increases (thereby weakening the impact of genetic drift)

Analysis: Carrying Capacity

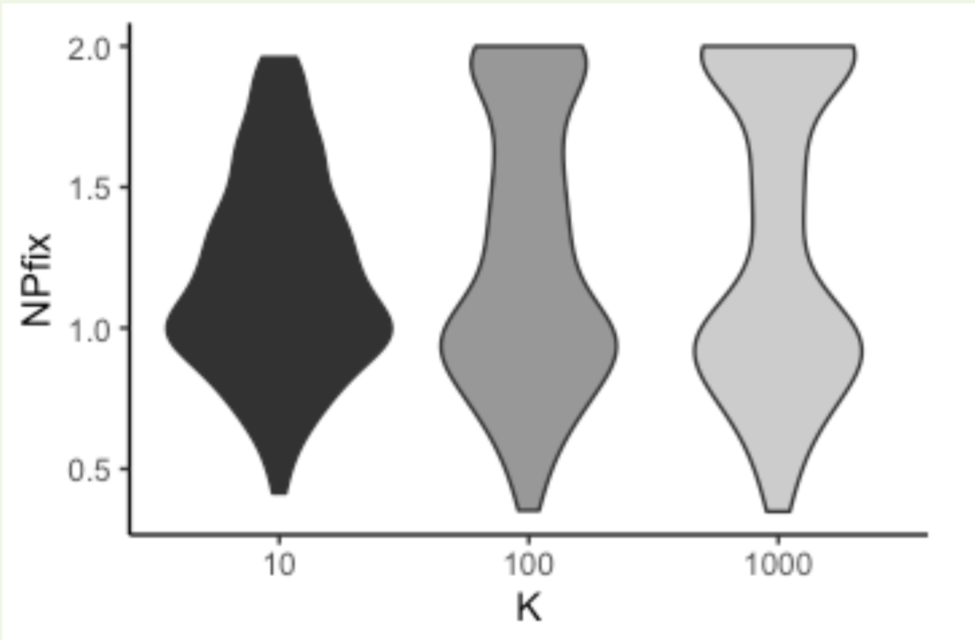

Figure 3. Normalized probabilities of fixation of bet hedgers (NPfix) at carrying capacities (K) 10, 100, 1000 across ranges of selection coefficient (S) and coefficient of variation (CV) have similar distribution at large K values. However, paired t-test on NPfix among pairs of different K with fixed G, S, and CV show statistically significant difference at α=0.05 among all three pairs, suggesting the carrying capacity of a population ***does influence the chance of survival for bet hedgers***.

Analysis: Coefficient of Variation

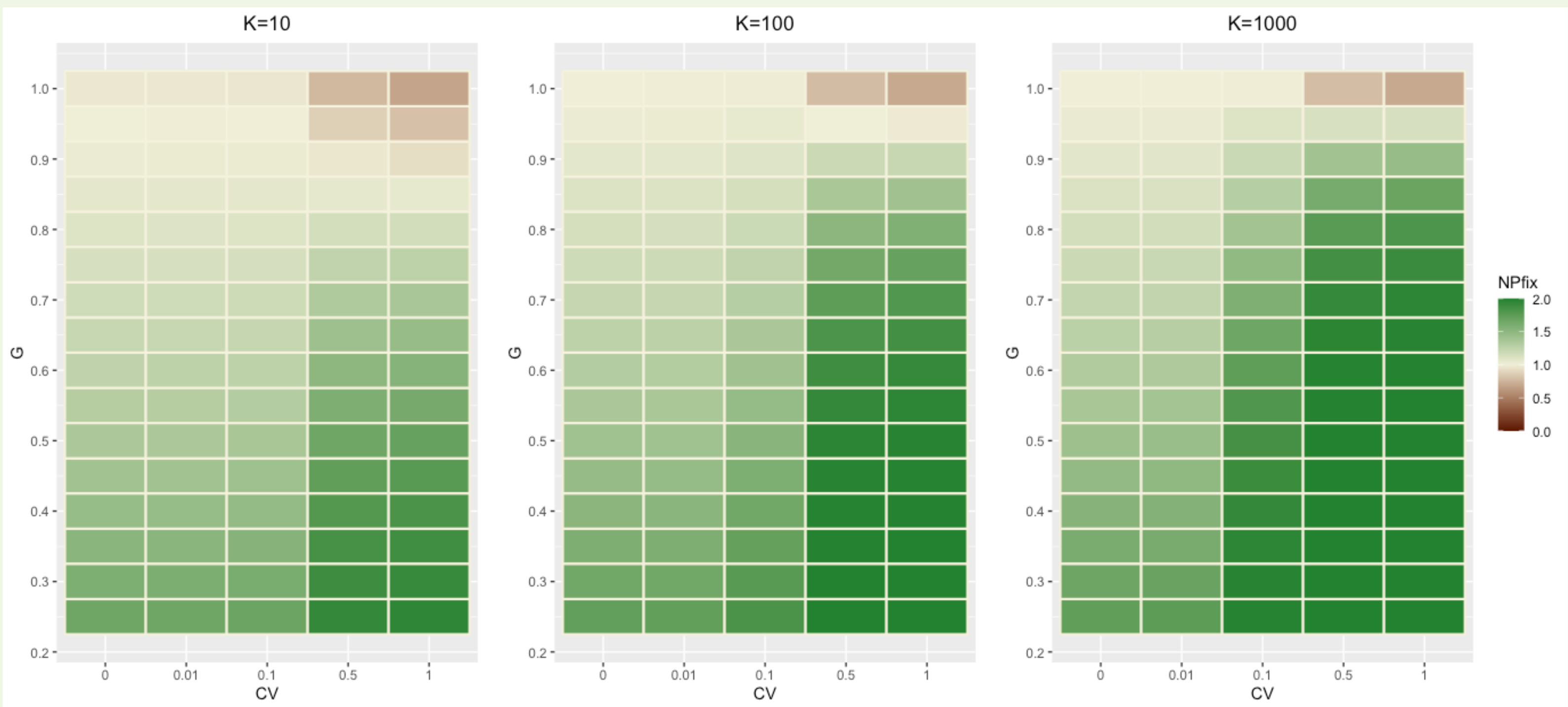

Figure 4. NPfix across all G, K, and CV at S=0(all native species). At all three carrying capacities, heatmaps* exhibit general trends of NPfix increasing as 1) G decreases; and 2) CV increases. We can infer that bet hedgers have a ***higher chance of survival*** when ***more seeds experience delayed germination*** under a ***more extremely varying environment***.

*[Note that at high germination rates, NPfix should approach 1.0 while the simulation results drop below 1.0 at higher CV values; this results from a design flaw of the model where a simulation ending with extinctions of both populations are tallied up as a WT fixation]

Analysis: Selection Coefficient

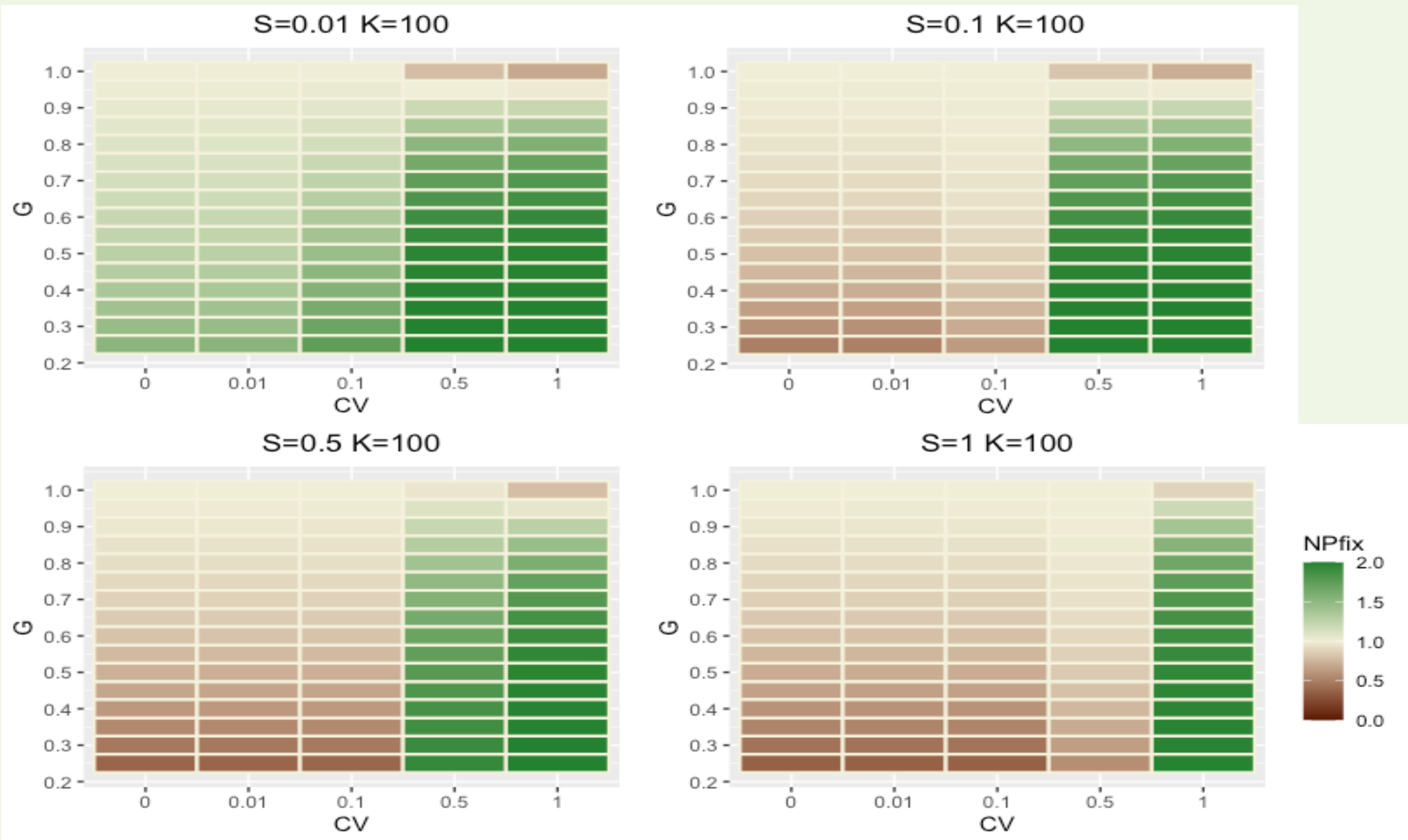

Figure 5. Normalized probabilities of fixation for all other S and K pairs. We see that ***as selection coefficient increases, the range where bet hedging is adaptive also changes***; when K is fixed, the heatmaps display a consistent trend of NPfix decreasing as S increases, suggesting that ***exotic species*** tend to be ***less adaptive when they bet hedge*** regardless of carrying capacity*.

*[Reproductions with selection coefficients lower than 0.2 simulate native species, those with higher ones exotic]

Discussion

Through simulating the competition between wild type and bet hedging populations, we acquire the normalized probabilities of fixation and can infer that

a) annual plant bet hedgers are generally more adaptive when the environment is highly variable, and that
b) exotic annuals are generally less adaptive than natives when they bet hedge.

Heatmaps above along with other statistics not shown enable us to analyze these results in various directions. Meanwhile, the current model can be modified to incorporate real world data and simulate competition of two bet hedgers of different species or the invasion of one single exotic seed into an established native population. Results of these upcoming analyses combined with field data and environmental data will help build a more comprehensive dictionary on the local biodiversity in any region.

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References: Olofsson Helen, Ripa Jörgen and Jonzén Niclas 2009Bet-hedging as an evolutionary game: the trade-off between egg size and numberProc. R. Soc. B.2762963–2969. https://doi.org/10.1098/rspb.2009.0500. https://massnrc.org/mipag/docs/MIPAG_FINDINGS_FINAL_042005.pdf